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(71) Applicant(s)
Institut Francais du Petrole

(Incorporated in France)

4 Avenue de Bois-Preau, 92502 Rueil-Malmaison, France

(72) Inventor(s)
Marie-Christine Cacas

(74) Agent and/or Address for Service
Fitzpatricks
Cardinal Court, 23 Thomas More Street, LONDON, E1 9YY, United Kingdom

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None

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(54) Modelling a stratified and fractured geological environment

(57) A geometric model of a stratified and fractured sedimentary environment is produced by means of interfaces having a common orientation representing the stacking of the strata and involves representing the fractures in the form of traces, each crossing at least one of the strata. Each trace is positioned and its extent delimited by random selection but complying with the fracture densities n(i) per unit length of each stratum as well as the proportions (s(i/i+1), s(i/i-1)) of traces crossing through the interfaces. The densities and proportions are determined by reference to the environment being modelled. The model obtained allows simulations of fluids flowing through the environment to be performed. This can be applied to the study of hydrocarbon displacements in subsurface deposits.

FIG.1

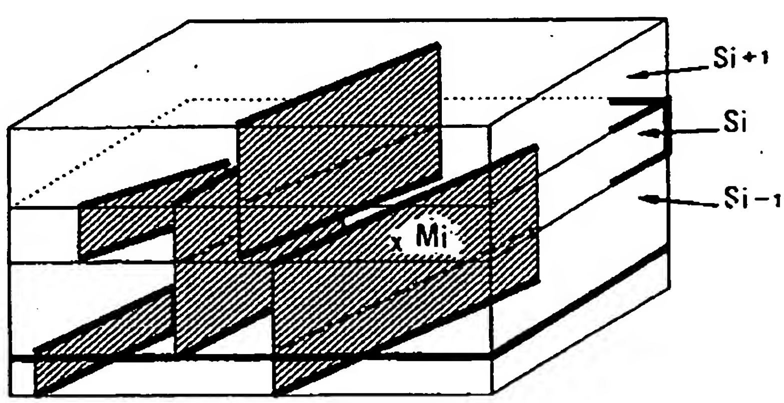

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FIG.1

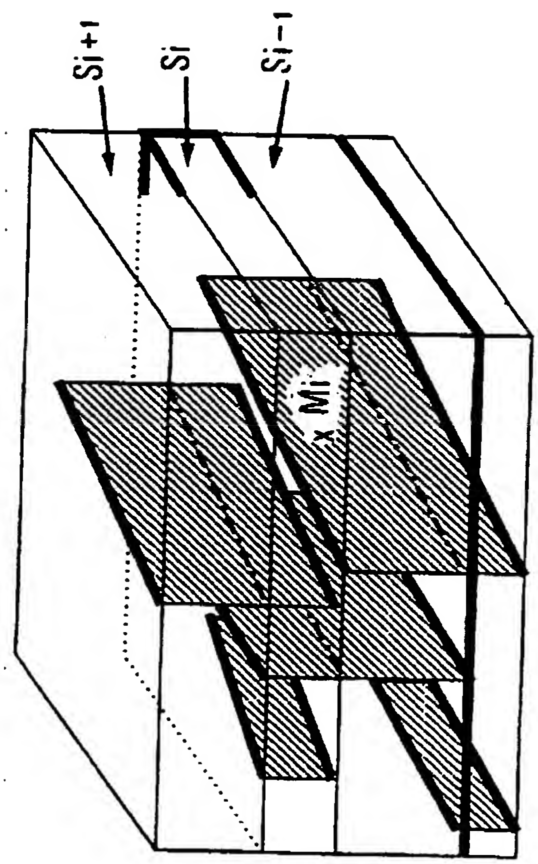


FIG.2A

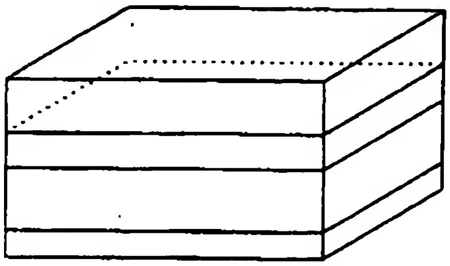


FIG.2B

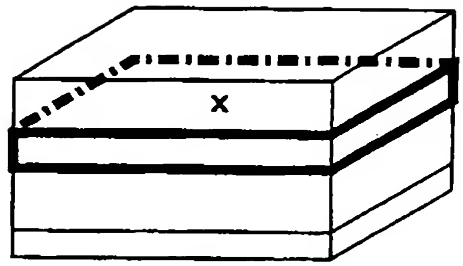


FIG.2C

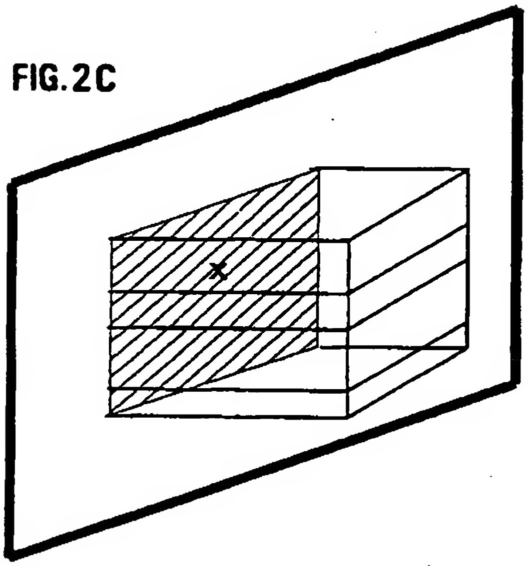


FIG.2D

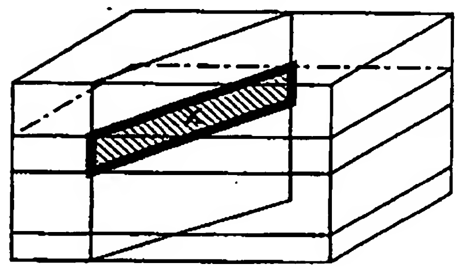


FIG.2E

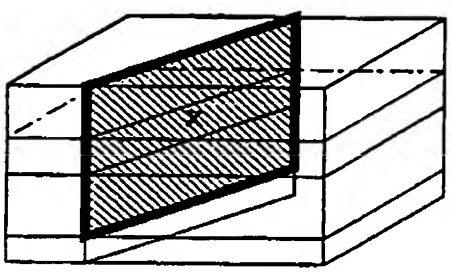
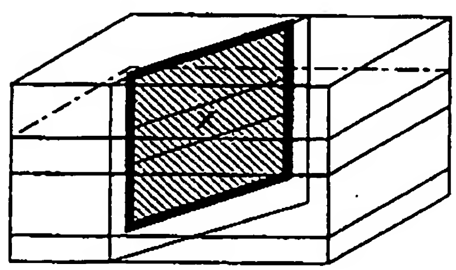


FIG.2F



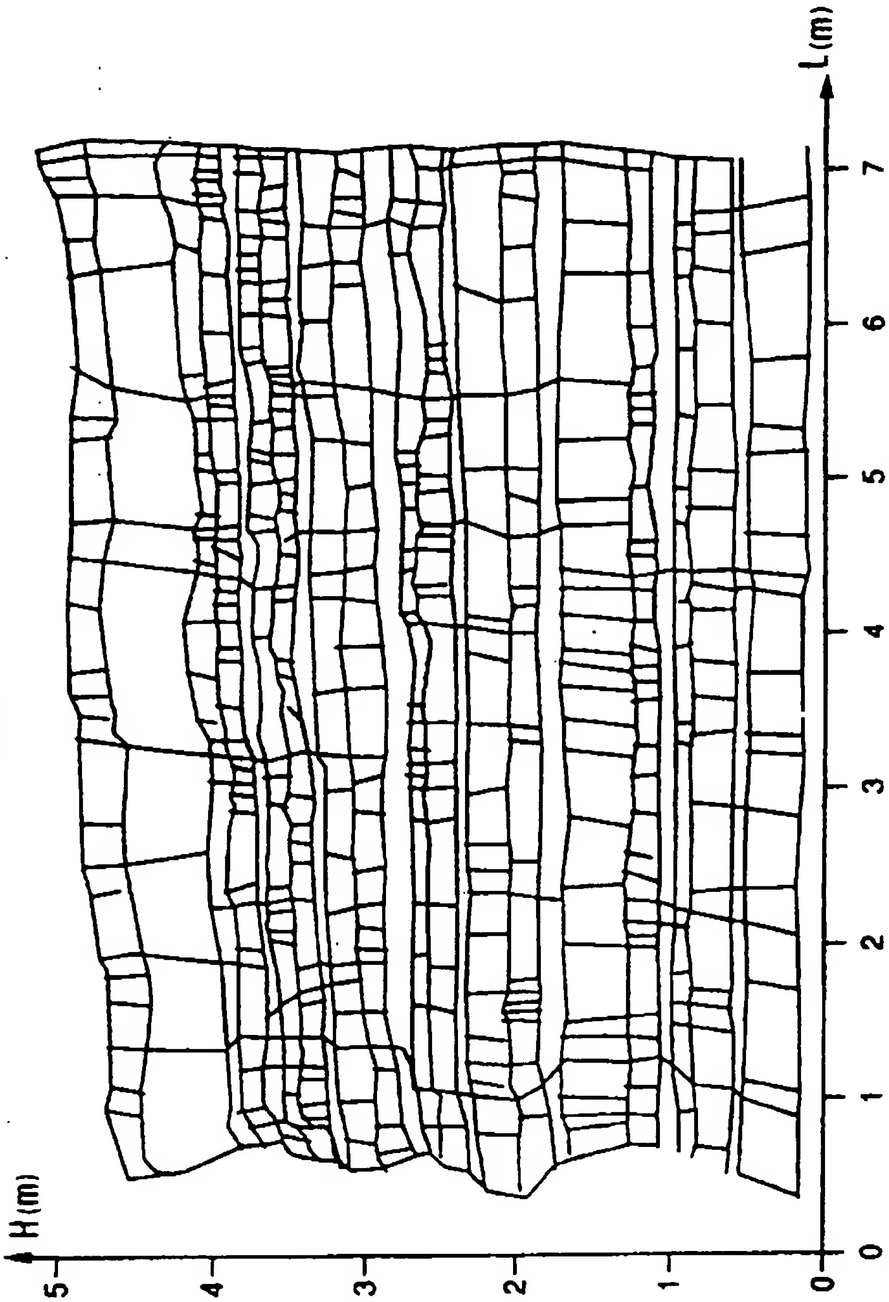
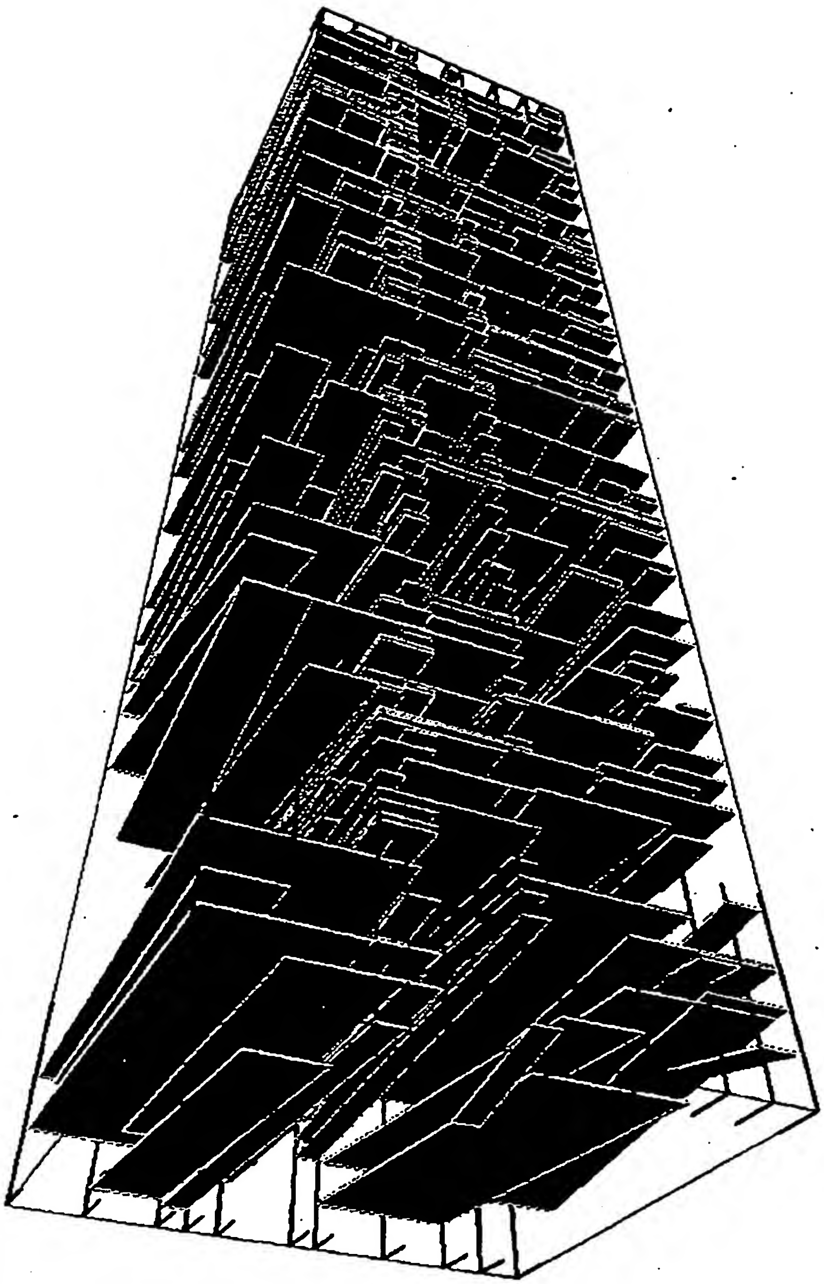


FIG.3

FIG.4



METHOD FOR MODELLING A STRATIFIED AND FRACTURED GEOLOGICAL ENVIRONMENT

The invention relates to a method for modelling a stratified and fractured geological environment in order to predict more accurately the pattern of fluid flows likely to occur through this environment.

The method of the invention is especially suitable for studying the hydraulic properties of fractured formations and for studying in particular the displacement of hydrocarbons in the subsurface deposits whose structure has been modelled.

It is convenient to use a model of a fractured rock to study how fluids will move in it. Usually, a conventional model of the fractured rock is built and a series of well-defined geometric objects placed in it. These objects, which may be fractures, for example, i.e. fault surfaces in the rock, can be reproduced using discs, ellipses or any other geometric surface. Using this approach, the geometrical model will be of the stochastic and discrete type. It is discrete because each fracture is individually represented in it by a geometric element. It is stochastic because the aim is not to represent a real, well-defined block of rock showing all the fractures that can be directly observed in the field. With this type of stochastic model, a rock block is represented by a synthetic block reproducing certain statistical properties

of the actual environment. In the synthetic block obtained, the dimensions and/or orientations of the fractures are consistent with the same statistical laws as those of a real block.

Once the model of the environment has been initially selected, the fluid flows are calculated by applying the laws of physics. The results of this calculation will then constitute a more or less approximate simulation of the behaviour of these same fluids in a real environment.

Clearly, the validity of the predictions made using this combined modelling system is largely dependent on the quality of the geometric model chosen, i.e. the resemblance between it and the actual environment it represents.

Geological surveys have shown that stratified environments are often damaged by fractures that are quasi-perpendicular to the planes of stratification or interface planes (Fig. 1), the ends of which stop at these planes. These joints are fractures in the rock in which there has been no relative movement in the sides of the fracture plane. Joint sets occur in the form of regularly spaced and quasi-parallel fracture planes. A given rock may have several joint sets which intersect to form a joint system. Such joints also have certain geometric properties, which have to be taken into account in the context of a petroleum environment:

- a) In a given material, it may be observed that the density of joints in each stratum is proportional to the thickness thereof. This property is applicable among others to any material whose strata are of variable thicknesses. Thin strata are characterised by a high density of joints; consequently, they form a passageway through which fluid flows will tend to pass by nature. The layers, on the other hand, have a lower density of joints and consequently form an obstacle to any fluid flow.

- b) The interfaces between strata constitute obstacles of a greater or lesser degree across the length over which the joints extend. Some inter-strata surfaces may be observed in which the joints stop systematically whilst others are largely crossed by them. These observations clearly illustrate that the possibilities for displacement of fluids across these interfaces very much depend on their nature. An interface which does not stop the continuation of joints will not form an impediment to a flow. In the reverse situation, it will stop the flow.

The aim of known geometric models of the discrete stochastic type is to represent homogenous environments. They are constructed by a method of random selection of values defining them, checked to ensure that they are consistent with the statistical properties of the environment being modelled. The geometric objects placed

in the model are disks, for example. To give an example, the conventional technique consists in:

- selecting at random the number of disks to be sited:
- selecting at random the position of these disks within the space of the model; and
- selecting at random the orientation and radius of each disk.

This approach works well for homogenous environments but cannot be readily applied to stratified environments where the structure determines the geometry of the fracture systems.

The method of the invention enables a geometric model of a stratified and fractured sedimentary environment to be constructed, producing a more accurate and more realistic simulation of the flow pattern likely to occur than can be produced with existing models.

It is characterised in that it consists in modelling the environment by means of interfaces having a substantially common orientation representing the stacking of the strata and a representation of the fractures in the form of traces, each crossing at least one of the strata (in which these strata would be surface portions such as quadrilaterals in a 3-dimensional representation and linear portions in 2-dimensional plane), each of these being sited and its extent delineated by random selection consistent with the fracture densities per unit of length

of each stratum and the sizes of traces crossing the interfaces, these densities and sizes being determined by examining the environment.

The method involves, for example, selecting for each trace a starting point in a stratum, positioning this trace from this starting point and determining how far it might extend to the adjacent traces, the position of the trace being chosen by random selection but consistent with criteria relating to the probable starting point and the probable extent to the adjacent strata defined by reference to the modelled environment.

Using the method of the invention it is possible to simulate not only the average density of the actual system and the orientations and actual sizes of the fractures, but also:

- to take account of the variation in fracture densities as a function of the thickness of the strata; and
- to represent the size and proportion of fractures crossing the interfaces to fractures stopping at these interfaces as observed in the field.

Other features and advantages of the method of the invention will become clear from the following description, given by way of example and not limitative in any respect, and from the attached drawings, in which:

- Figure 1 shows a model of a stratified

environment in which the fractures are represented by oblique surface portions;

- Figures 2a to 2f show various stages in the modelling process of the invention;

- Figure 3 shows a digitised image of a natural stratified and fractured environment, an analysis of which will allow the faulting density values of the strata to be determined as well as their propagation through the interfaces between the strata; and

- Figure 4 shows an example of a constructed reservoir model allowing a faithful simulation of the flows through the modelled reservoir.

In order to represent a stratified and fractured sedimentary structure in three dimensions, a model made by superposing Ns strata (Fig. 2a) is used, in which the interfaces between the strata are represented by planes. In this model, the fractures are represented by surface portions (such as quadrilaterals, for example) that are not parallel to the interfaces and which stop when they meet two specific interfaces of the model. The different surface portions are defined one by one by the sequence of processes defined below.

- 1) A stratum Si designated as the "initiation stratum" is selected from among the Ns strata and the probability of this stratum of rank i of being selected is designated as being pInit(i).

- 2) A point or "grain" Mi is selected at random within the stratum Si (Fig. 2b).

- 3) A surface portion is placed in the model but not parallel to the strata passing through this grain and with a given orientation which may be chosen at random, for example (Fig. 2C). This surface portion is restricted in height by the upper and lower interfaces of the initiation stratum but is not restricted in terms of width (Fig. 2d)

- 4) The height to which this surface portion might extend to the interfaces of the adjacent strata Si-1 and Si+1 is selected at random. The probabilities of the surface portion's extending to the stratum Si-1 and Si+1 are given respectively by p(1,i-1) and p(i,i+1).

- 5) The preceding operation is repeated to ascertain whether the course of the surface portion continues to the strata Si-2 and Si+2, then Si-3 and Si+3, etc. until the interfaces interrupting the extent of the fracture are reached (Fig. 2e).

- 6) Finally, the surface portion representing the fracture is "cut" to a given length 1, possibly obtained by random selection, whilst remaining centred on the initial grain (Fig. 2f).

The random selection of the positioning and extent of each surface portion is governed by two types of parameter:

- the probability factor pInit(i) of initiation in

the stratum Si; and

- the probabilities p(i,i-1) and p(i,i+1) of the fractures in a stratum Si extending to the adjacent strata Si-1 and Si+1.

The value of these parameters is very closely linked to the configuration of the stratified and fractured environment being modelled.

By carrying out a preliminary survey of the environment, using digitized maps and photos such as illustrated in Fig. 3, for example, it is possible to determine:

- the faulting densities n(i) in the various strata, i.e. the average number n(i) of fractures encountered per unit of length in the plane of the stratum Si; and

- the actual conditions whereby the fractures are interrupted at the interfaces. For each stratum, the interruption conditions are expressed by two values s(i/i+1) and s(i/i-1), whereby the first represents the number of fractures encountered per unit of length in the plane of stratification which stop at the interface between the strata Si and Si+1 and the second represents the corresponding number of fractures which stop at the interface between the strata Si and Si-1.

The parameters pInit(i), p(i,i-1) and p(i,i+1) are adjusted in two stages on the basis of the actual

conditions and densities recorded.

Firstly, the values of probability p(i,i-1) and p(i,i+1) which meet the conditions of interruption at the interfaces are sought and then the values pInit(i) that are to be used to comply with the imposed density conditions are derived from these.

a) It can be shown that the probability p(i-1,i) of a fracture's extending across the interface between the strata Si-1 and Si can be expressed in the

$$p(i-1,i) = \frac{s(i/i+1)+n(i).[p(i/i-1)-1]}{s(i/i+1)+[n(i)+s(i/i-1).[p(i,i-1)-1]]} \qquad (1)$$

For each interface plane, values p(i, i-1) and p(i-1, i) are chosen within the range between 0 and 1 and such as to verify the equation (1) so as to be consistent with the conditions of interruption at the interfaces.

b) The initiation probabilities also have to be verified by the following relations 2:

$$n(i) = N.\left\{ \sum_{k=1}^{i-1}\left[pInit(k).\prod_{l=k}^{i-1} p(i-1,i) \right] + pInit(i) + \sum_{k=i+1}^{n}\left[pInit(k).\prod_{l=k}^{i+1} p(i,i-1) \right]\right\}$$

In this equation,

$$N = \sum_{i=1}^{Ns} n(i)$$

and Ns represents the number of strata in the model.

Once the probabilities p(i,i-1) and p(i,i+1) are obtained, the initiation probabilities pInit(i) are respectively determined in the various strata, which are solutions of the linear system of equations above. By adopting the values obtained, it will be possible to comply with the imposed fracture densities ascertained in the preliminary survey.

<u>Specific instance</u>: It may be made a rule that the surface portions be propagated in a single direction only, for example from the lower strata to the upper strata.

In this case:

$$p(i,i-1)=0$$

and

$$p(i,i+1)=n(i+1)-s(i+1/i)$$

are selected.

The initiation probabilities pInit(i) are then explicitly calculated by the relations:

$$pInit(i) = \frac{n(i)}{N} - \sum_{k=1}^{i-1}\left[pInit(k).\prod_{l=k}^{i-1} p(l,l+1)\right]$$

CLAIMS

1. A method for producing a geometric model of a stratified and fractured sedimentary environment, which consists in producing a model of the environment by means of interfaces having a substantially common orientation representing the stacking of the strata, wherein it involves representing the fractures in the form of traces, each crossing at least one of the strata, each trace being positioned and its extent delimited by random selection but complying with the fracture densities n(i) per unit of length of each stratum as well as the proportions (s(i/i+1), s(i/i-1)) of traces crossing through the interfaces, these densities and proportions being determined by reference to the environment being modelled.

2. A method as claimed in claim 1, wherein where the modelled environment is three-dimensional, traces consisting of plane portions are positioned.

3. A method as claimed in claim 1 or 2, wherein it consists in selecting for each of the traces an initiation position in a stratum (Si), positioning this trace from this initiation position and determining its possible extension to the adjacent traces, the positioning of the trace being selected at random but consistent with the initiation probabilities (pInit(i)) and the probabilities of extension to the adjacent strata (p(i, i-1), p(i, i+1)), defined by reference to the environment being

modelled.

4. A method as claimed in claim 3, wherein for each of the traces, the probability of extension to the adjacent traces (p(i,i-1), p(i,i+1)) verify the condition:

$$p(i-1,i) = \frac{s(i/i-1)+n(i).[p(i/i-1)-1]}{s(i/i-1+[n(i)+s(i/i-1).[p(i,i-1)-1]]}$$

5. A method as claimed in claim 3 or 4, wherein the initiation positions of the traces are selected so that their initiation probabilities (pInit(i)) verify the relations:

$$n(i) = N.\left\{ \sum_{k=1}^{i-1}\left[pInit(k).\coprod_{l=k}^{i-1} p(i-1,i) \right] + pInit(i) + \sum_{k=i+1}^{n}\left[pInit(k).\prod_{l=k}^{i+1} p(i,i-1) \right] \right\}$$

6. A method as claimed in one of claims 3 to 5, wherein it also consists in defining the length of each surface portion along a direction parallel to the direction in which the strata extend.

7. A method substantially as hereinbefore described with reference to the drawings.

Application No: GB 9607273.1
Claims searched: All

Examiner: Matthew Gillard
Date of search: 15 July 1996

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.O): G4A AUA, AUXX

Int Cl (Ed.6): G01V 1/00, 1/28, 1/30; G06F 17/00; G06G 7/48, 7/50, 7/57

Other: On-line: WPI, GEOLOGY, COMPUTER

Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
	NONE	

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.